EEAR: An Energy Effective-Accuracy Routing Algorithm for Wireless Sensor Networks

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Abstract： In this paper, Energy Effective-Accuracy Routing (EEAR) protocol is suggested for wireless sensor networks on the basis of energy saving while communication between sensor nodes on the whole network EEAR can conserve energy until keeping communication and routes leading to sink, by data-center gradient diffusion routing protocol. This is realizing by detection and turning on/off radio frequency and other elements of extra sensor nodes. EEAR, which is inspired from combining *Gradient-Based Routing (*GBR) route finding and Naps topology management protocol while applying both protocols advantages, keeps nearly constant level of routing accuracy with no need to geographic location information. After establishing communicative layers towards the sink while conserving inter-layer communication, this protocol puts extra nodes in sleeping state. In fact, in each layer, a node can go to sleep state by detecting some other nodes that can do communication duty on behalf of that node. Despite conformity with all data delivery models, EEAR produces considerable results in continuous and event-driven models towards query-driven model. In this paper we have implemented EEAR and compared it with some other methods, including GBR, Naps and GAF. Simulation results show that EEAR without requiring position information, performs at least as well as location based protocols in terms of topology control, routing and energy saving, and increases the packet delivery amount and decreases average packet delay.

[Farzad KIANI, Ali AGHAEIRAD, Malik Kemal SIS, Alp KUT, Adil ALPKOCAK. **EEAR: An Energy Effective-Accuracy Routing Algorithm for Wireless Sensor Networks.** *Life Sci J* 2013;10(2):39-45].(ISSN:1097-8135).http:www.lifesciencesite.com. 7

Keywords: Wireless sensor network, energy effective-accuracy, energy-aware, routing

1. Introduction

Wireless Sensor Network (WSN) is composed of a large number of sensor nodes, which are densely deployed either inside the phenomenon or very close to it. Any sensor sends collected data by radio transmitter to the sink either single hop (directly) or hop-by-hop [1, 13].

Networking unattended sensor nodes are expected to have significant impact on the Effective of many military and civil applications such as combat field surveillance, security, disaster management and underground mining. These systems process data gathered from multiple sensors to monitor events in an area of interest [1, 13].

As usual, each sensor node consists of four main components: first, a sensing subsystem including one or more sensors (with associated analog-to-digital converters) for data acquisition; second, a processing subsystem including a micro-controller and memory for local data processing; third, a radio subsystem for wireless data communication; and fourth, a power supply unit. Depending on the specific application, sensor nodes may also include additional components such as a location finding system to determine their position, a mobilizer to change their location or configuration (e.g., antenna's orientation), and so on. [2, 13]

The power supply unit often consists of a battery with a limited energy. In addition, it could be impossible or inconvenient to recharge the battery, because nodes may be deployed in a hostile or unpractical environment. On the other hand, the sensor network should have a lifetime long enough to fulfill the application requirements.

For better management of power, it is better in these networks, to have some information on division of energy consumption rate among different parts of each node. Although energy consumption rate among parts of each node depends on that especial node structure and its application type and work domain of the network, but the following remarks are generally hold: [3]

- The communication subsystem has energy consumption much higher than the computation subsystem. It has been shown that transmitting one bit may consume as much as executing a few thousands instructions. Therefore, communication should be traded for computation [5].
- The radio energy consumption is of the same order of magnitude in the reception, transmission, and idle states, while the power consumption drops at least one order of magnitude in the sleep state. Therefore, the radio

should be put in sleep state (or turned off) whenever possible [5].

- Depending on the specific application, the sensing subsystem might be another significant source of energy consumption, so its power consumption has to be reduced as well [5].

Knowing these features, it is clear that an efficient transition of packets among nodes and sink would have considerable effect on energy consumption rate and would increase sensor nodes life span and as a result network life length.

In this paper, we present a new energy-aware routing protocol to prolong the life time by turning off unnecessary sensor node's radio components in the network without much affecting the level of routing accuracy. EEAR protocol uses the Gradient Data Centric and Connectivity Driven Topology Management Schemas at the same time, and gains the benefits of both for keeping nearly constant level of routing accuracy.

Simulation results show that EEAR outperforms the traditional energy-aware routing approaches in terms of network lifetime, packet delivery, average packet delay and load balancing ratio.

The remainder of the paper is organized as follows. Section 2 provides challenges on WSN routing and energy conservation and brief overview of the related work. Section 3 explains the operation of EEAR routing protocol. Section 4 describes simulation tool abilities and structures. Section 5 compares the performance of EEAR and the protocols used in same schemes to represent experimental results. Finally, conclusions and open issues are discussed in Section 6.

2. Challenges at Energy Issue in WSN

Routing and energy conservation in sensor networks is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad-hoc networks. Based on the sensor node's architecture and power breakdown, several approaches have to be exploited, even simultaneously, to reduce power consumption in WSNs. At a very general level, we identify three main enabling techniques, namely, duty cycling, data-driven approaches, and mobility [5].

Duty cycling is mainly focused on the networking subsystem. The most effective energy-conserving operation is putting the radio transceiver in the (low-power) sleep mode whenever communication is not required. The second issue arises whenever the consumption of the sensing subsystem is not negligible. Data driven techniques are designed to reduce the amount of sampled data by keeping the sensing accuracy within an acceptable level for the application. In case some of the sensor nodes are mobile, mobility can finally be used as a tool for reducing energy consumption (beyond duty cycling and data-driven techniques).

With respect to division of energy consumption rate among different parts of each node, duty cycling techniques saves more energy than others. Duty cycling is applicable in two ways, topology control and power management [5].

Topology control schema exploits node redundancy, which is typical in sensor networks, and adaptively selects only a minimum subset of nodes to remain active for maintaining connectivity, where it is possible by one of the two, connective-driven or location-driven protocols. On the other hand, with power management schema active nodes (i.e., nodes selected by the topology control protocol) do not need to maintain their radio continuously on. They can switch off the radio when there is no network activity. Topology control and power management are complementary techniques that implement duty cycling with different granularity. We use connective-driven topology control approach to develop our protocol.

Naps protocol [11] is also a connective-driven topology control that thins a network to a desired density of nodes per unit area without knowledge of the underlying density or node location. Naps select a rotating set of awaking nodes of a desired density. Although Naps is a robust topology management protocol but has no infrastructure for packets routing.

GAF [9] is another duty cycling topology control protocol that uses location information. GAF is proposed to alleviate energy burdens for routing demands. From this topology, divide up the surveyed area into a virtual grid. This virtual grid's cells contain nodes that are functionally equivalent of routing to one another. Any node in a virtual grid cell may become the leader and handle all routing traffic, allowing other nodes to sleep for extended periods of time and conserve energy. GAF is one of the few protocols that simultaneously reduce energy consumption and produces good results for the routing of packets. One of the biggest problems of this protocol is the need for knowing the position information of the nodes.

On the other hand, some features affect routing structure. First of all, it is not possible to build a global addressing scheme for the deployment of large number of sensor nodes. Therefore, classical IP-based protocols cannot be applied to sensor networks. Second, in contrary to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple regions (sources) to a particular sink. Third, generated data traffic has significant redundancy, since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization. Fourth, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management [4].

Due to such differences, many new algorithms have been proposed for the problem of routing data in sensor networks. Almost all of the routing protocols can be classified as data-centric, hierarchical or location-based, there are few distinct ones based on network flow or QoS awareness [4].

Data-centric protocols are depending on the naming of desired data, which helps in eliminating many redundant transmissions. Hierarchical protocols aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy. Location-based protocols utilize the position information to relay the data to the desired regions rather than the whole network [4]. Our proposed protocol will be operating based on the gradient data-centric approach.

Direct diffusion [7] and GBR [8] are data-centric protocols. Generally, these protocols start with placing requests as interests by the sink. Sources are eventually found and satisfy interests and intermediate nodes route data toward sinks. Leach [12] and GAF [9] respectively are known methods of hierarchical and location base protocols.

3. Proposed Protocol: EEAR (Energy Effective-Accuracy Routing)

The protocol is a new energy-aware routing protocol for WSNs to prolong the life time by turning unnecessary sensor node's radio components off in the network without much affecting the level of routing fidelity.

EEAR, as a duty cycling method, exploits node redundancy and uses connective-driven topology management schema. It adaptively selects only a minimum optimal subset of nodes to remain active for maintaining connectivity. Selected active nodes undertake communication duty of other sleeping neighbor nodes and diffusing data packets through sensor nodes to the sink without route discovery. EEAR is connective-driven topology management and routing protocol and works without the need for geographic location information.

3.1. Network Deployment

We consider a network of static (e.g. immobile) energy constrained sensors that are redundantly deployed over a flat region. Assume that all nodes in the network have the same architecture and design fundamental and all nodes are participating in the network and forward the given data packets to a particular command center (sink). Additionally, these sensor nodes have limited processing power, storage and energy.

We propose EEAR, based on an event-driven data delivery model and data packets are provided when each node understand a phenomenon in its sampling environment radius.

3.2. Phases in EEAR

Two phases take the responsibility of putting this protocol into action. The first phase is Layering-State and the second phase is Connectivity-State.

At first phase EEAR puts whole network nodes into virtual layers, each layer is distinguished by sensor nodes interest rates, differences of nodes interest rates forwards data packets between virtual layers up to the sink. These virtual layers are established through broadcast of interest packet among network nodes. After expanding the nodes in the monitoring area, the sink starts to broadcast interest packet. This packet includes interest step that the sink starts it from zero. All nodes, available in the network, are waiting for receiving interest packet and each node increases one unit to interest value after getting the packet, and conserves it as its interest step rate. After performing all above operations each node re-broadcasts interest packet to its neighbors. The nodes, who have determined their interest rate, drop interest packets if they re-receive it, which causes the interest packet to forward deep in the whole environment. Figure 1 shows different steps of Layering-State phase of EEAR protocol. By completing interest packets broadcast, virtual interest layers are established among network nodes. Each layer includes the nodes with the same interest value.

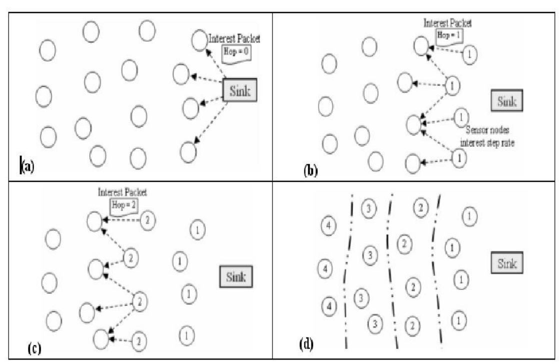

Figure 1. Different steps of first phase of EEAR to detect layers

After generating layering, at the second phase all nodes in each layer are modeled as a random graph. Then we start to enforce duty cycling by exploiting the percolation theory on this random graph. In this phase, EEAR strives to keep the network connected by keeping enough number of representative nodes in active mode for each virtual layer. These representative nodes undertake communication duty of other a sleep neighbor nodes in the same layer. For this purpose we use two parameters T and C. T represents duty cycling period time and C determines the degree of internal communications. Each node with C active neighbors in the same layer, in own radio radius devolve its communication duty to those active nodes and goes to sleep state, To do so, each node spots considers time periods with duration T, and waits for a random amount of time t_v, which uniformly distributed into the range [0, T). After t_v, a node operates on the basis of T in the following way.

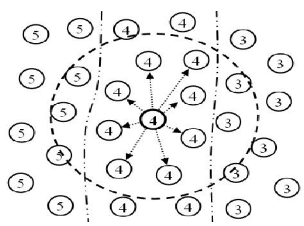

Figure 2. Selected neighbors by a typical node to send HLEO packets

First, it broadcasts a HLEO message to advertise its activation to neighbor nodes in the same layer. Figure 2 shows selected same layer neighbors by a typical node to send HLEO packets. Then, it listens for HLEO messages sent by other nodes.

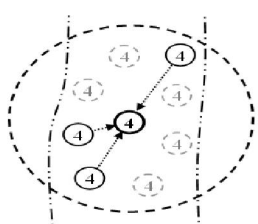

Figure 3. Received HLEO packets illustrate an activation of other nodes

During node operations over T, node can goes to sleep state until the next time period as soon as it receives C activation HLEO messages from its neighbors in the same layer. Otherwise, it remains active for all the time period T.

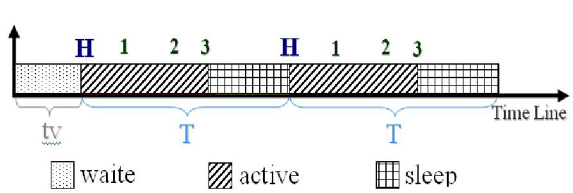

Figure 4. Activation time line for a typical node

For example, as shown in Figure 4, if at a typical network, C is equal to 3; each node after publishing its activity, sends its own HLEO packet and upon receiving 3 HLEO messages goes to sleep state until beginning of the next period.

3.3. Routing in EEAR

EEAR uses Data-Center GBR Schema to flow data packets through multiple layers to the sink without route discovery. Each node in active state sends its own packet to at least one of its active neighbors in next layer that have the less interest step. Next, the node in the lower layer takes the responsibility and sends the packet to the next lower layer to near the sink, after some steps with out the need to end to end path; the packet will reach to the sink (Figure 5).

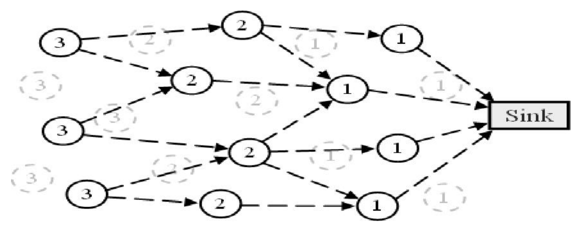

Figure 5. Packet routing in active nodes

The nodes, which are in the sleep state, may want to send packet in this case they can send the packet to one of their adjacent active nodes. This leads to considerable decline in packet sending delay. In fact, sleep state approach in this protocol is different from traditional approaches. Available nodes in sleeping state (whose radios are inactive) can activate their radio components for a moment by conserving state title (sleeping state) to send packets to one of active neighbors in same layer (Figure 6).

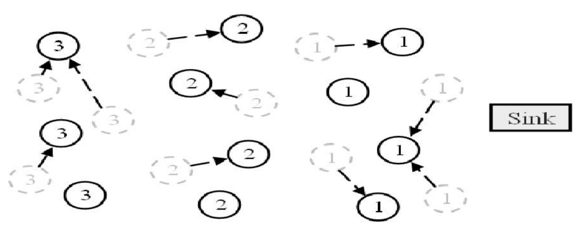

Figure 6. Packet routing in sleeping nodes

There is no stable path to forward packets in EEAR. This means that, paths that a packet will get through from a particular node to the sink will change in different times. Path instability in some cases is desirable due to the increased reliability. Some exceptions could be occurring in terms of routing that we investigate some of them. An active node might not found active neighbor with less interest step in own radio range, therefore it can send data packet to one of neighbors in same layer or buffer the packet until a node with that situation is appear.

On the other hand, for each sleeping node, it is assured that there exist one or more active nodes around it. If any sleeping node could not find active node in its neighborhood, means that some of active neighbors active nodes have been broken or their energy have ended, so sleeping node get awaken, and takes the responsibility of its own communication duty.

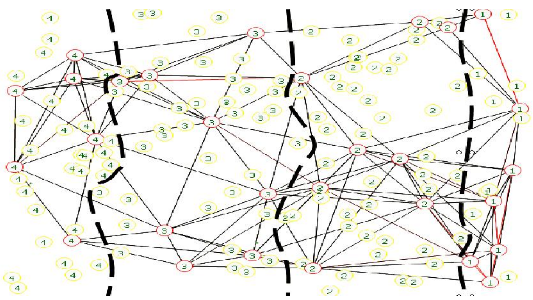

Figure 7. Communications and Topology schema in EEAR in a typical network

3.4. Failing in EEAR

When a node breaks down or its energy is over, alike to figure 8, other nodes on the same layer undertake its packet delivery duty. It should be noted that, existence of several routes, as a result of path instability, causes a Don't-Stop transmission of packets to the sink.

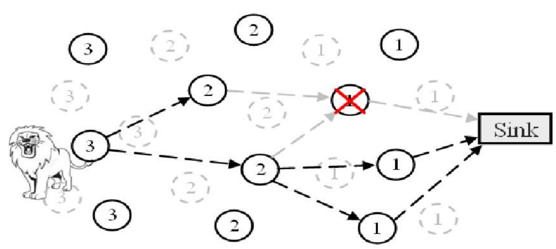

Figure 8. Sensor network continues to forward packets when some nodes fail

On the other hand by completion of the adjacent sleeping nodes time-cycle, they wake up and we achieve former connectivity degree.

4. Simulation

To simulate and compare the proposed protocol, a WSN simulator is used. This simulator has been designed for topology control and management and provides appropriate conditions for surveying WSN protocols. We provide GBR, Naps and GAF protocols in this simulator and compare the results with our protocol.

During different simulations and various surveys, 200, 250, 300, 350, and 400 sensor nodes were distributed uniformly in a 600*600 m^2 area. Initially, $2*10^5$ energy unit is assigned to each node. The effective radio range is considered 120 meter and radius of the sampling environment is 60 meter for each node. The energy dispatching model in battery power drain for radio consumption is considered stable and fixed for transmission; reception and standby (idle) states of 40 units. This figure for sense consumption is 20 units for each instruction cycle. Data packets are provided when each node understands a phenomenon in its sampling environment radius.

All experiments are repeated several times with different random seeds and different random node topologies but at the same situation for all considered protocols. For the evaluation of protocols the following three metrics have been chosen. These metrics are Packet Delivery Amount, Average Packet Delay and Network Life Time. Each metric is evaluated as a function of the topology size, the number of nodes deployed, and the data load of the network.

The results of experiments are shown in the figures 9-11. Figure 9 shows the packet delivery percentage with respect to number of nodes. As can be seen, EEAR works better than all except GBR. This is because all nodes in GBR are active and there is no any kind of topology control management (to put nodes in a sleep state). So despite the good performance of GBR, lack of saving energy is a big problem.

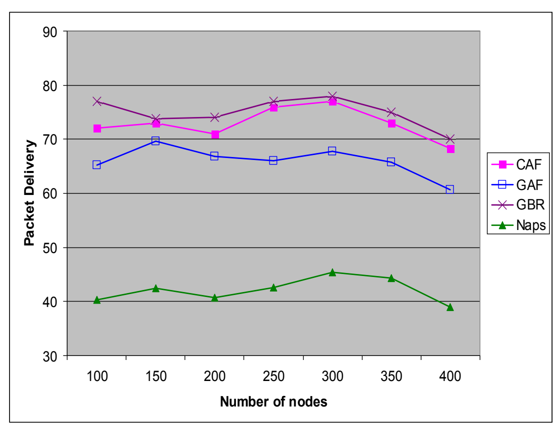

Figure 9. Packet Delivery

Figure 10 shows average packet delay with respect to number of nodes. Again it is shown that, has better results, i.e., low delay than other protocols. The reason is that packets total path steps for EEAR in comparison with other protocols step counts are less, due to the distance within the layers.

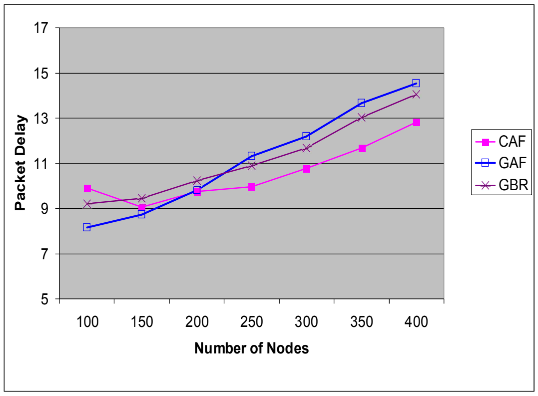

Figure 10. Average Packet Delay

Finally figure 11 shows network life time with respect to number of nodes. As shown in the figure, EEAR has life time as well as other topology management protocols when we have a large network density.

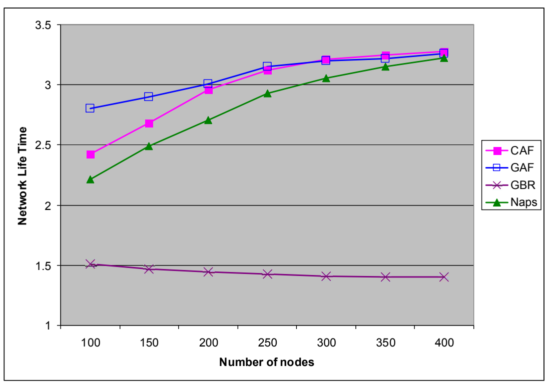

Figure 11. Network Life Time

EEAR utilizes the redundancy as a positive criterion, and puts more nodes in sleep state.

5. Conclusion

In this paper, we have introduced EEAR an energy-aware routing protocol that prolong the life time by turning off unnecessary sensor node's radio components in the network without much affecting the level of routing fidelity in location-unaware WSNs.

The EEAR protocol is connective-base topology management and routing protocol and works without the need for geographic location information. Another type of topology management protocols are location-driven protocols in which sensor nodes require to know about their position via certain tools like GPS units. GPS is quite expensive and energy consuming so it is often unfeasible to install it on all nodes.

It should be noted that popular available sensor platforms lack hardware suitable to acquire location information. Therefore, the connectivity-driven protocols which do not need GPS and them only require information derived from local measurements, are generally preferred.

Experimental results show that EEAR without the need for position finding devices, performs at least as well as location based protocols in terms of topology control, routing and energy saving, and increases the packet delivery amount and decreases average packet delay. Of course, it should be noted that during the simulation, energy consumption of location finding devices for location-driven protocols has not considered.

As there is no routing table in EEAR, data packets flow by interest hops, thus paths are not stable. For a future work, we can reinforce hops and find better routes to forward packets. On the other hand we can extend EEAR to support mobile sensor nodes that which change their interest levels.

Although EEAR is a data-centric protocol, it may also be considered as a hierarchical protocol. Each sleeping node is ensured of existence of active nodes beside. Therefore, all non-active nodes are located around active nodes and one can consider active node as cluster-head. In EEAR, data aggregation or data fusion, similar to hierarchy structures, have not been predicted, though, one can apply these issues for active or sleep nodes.

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